(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 244 012 B1

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: **13.09.95 Bulletin 95/37**

(51) Int. Cl.[6]: **G03B 41/00**, G03F 9/00, B25J 7/00

(21) Application number: **87200720.8**

(22) Date of filing: **16.04.87**

(54) **Positioning device.**

(30) Priority: **29.04.86 NL 8601095**

(43) Date of publication of application: **04.11.87 Bulletin 87/45**

(45) Publication of the grant of the patent: **13.09.95 Bulletin 95/37**

(84) Designated Contracting States: **AT CH DE FR GB IT LI**

(56) References cited:
EP-A- 0 097 380
EP-A- 0 109 718
EP-A- 0 147 169
EP-A- 0 196 711
US-A- 3 361 018
US-A- 3 783 707
US-A- 4 575 942

(56) References cited:
IBM TECHNICAL DISCLOSURE BULLETIN, vol. 15, no. 12, May 1973, pages 3889-3890,New York, US; J. ARONSTEIN et al.: "Frictionless x, y, z and thetamicropositioning table"
R. BREITINGER: "Lösungskataloge für sensoren", part I, page 46
DE CONSTRUCTEUR, no. 10, October 1983, pages 84-87; R.H. MUNNIG SCHMIDT et al.:"Het gebruik van lineaire gelijkstroommotoren in snelle en nauwkeurigepositioneer inrichtingen, zoals X-Y tafels"

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EP 0 244 012 B1

Description

The invention relates to a positioning device comprising a first, upper and a second, lower support which are coupled to each other by means of at least two elastically deflexible rods acting together as a parallelogram mechanism, said first upper support being displaceable with respect to a base of the device in directions parallel to coordinate directions X and Y of an orthogonal coordinate system X, Y, Z, said first upper support further being displaceable with respect to said second lower support in a direction parallel to the Z-direction by means of a Z-actuator.

The invention further relates to an optical lithographic device provided with a positioning device according to the invention.

In a known positioning device of the kind mentioned in the opening paragraph (from IBM Technical Disclosure Bulletin, Vol. 15, No. 12, May 1973, p. 3889-3890) movement parallel to the Z-direction is accomplished by a piezoelectric actuator. Movements of the upper support in X- or Y-direction by flexure of bimorph springs necessitates a Z-motion compensation by the piezoelectric actuator.

In a further known positioning device (see the book "Lösungskataloge für Sensoren", Part I, of R. Breitinger, 1976, p. 46, ESBN 3-7830-0111-0), the upper support can be displaced with respect to the fixedly arranged lower support over a comparatively large distance parallel to the Y-direction with a simultaneous displacement over a comparatively small distance in a direction parallel to the Z-direction. For applications of the known positioning device in which, besides a displacement parallel to the Z-direction also a displacement independent thereof parallel to the X- and Y-directions is desired, a movement of the two supports together as a whole parallel to the X- and Y-direction, respectively, is conceivable. A positioning device for the X- and Y-directions without the possibility of displacement parallel to the Z-direction is known per se from the magazine "De Constructeur" of October 1983, No. 10. In an article in this magazine (p. 84-87, see Fig. 4) of R.H. Munnig Schmidt and A.G. Bouwer, an X-Y-φ-table is described comprising one electric linear motor for the X-direction and two electric linear motors for the Y-direction and the φ-direction.

A positioning device for displacing objects, such as semiconductor substrates, by means of which such an object can be displaced in the X- and the Y-direction as well as in the Z-direction, is known from US-PS 4,485,339. The displacement in the Z-direction is obtained by means of three actuators of the electrodynamic type. The displacement in the Z-direction is obtained by means of three actuators without the table or object holder being tilted is comparatively complicated and also expensive.

The invention has for its object to provide a positioning device in which the upper support can perform displacements parallel to the Z-direction which is independent of the displacements of the upper support parallel to the X- and Y-directions by simple, robust and reliable means which do not introduce play, friction or hysteresis.

A positioning device according to the invention is defined in claim 1. Due to the fact that for displacements of the upper support parallel to the Z-direction, the comparatively stiff actuator pushes itself and the lower support away parallel to the Y-direction with respect to the upper support, and the lower support experiences a minimum resistance owing to the aerostatic bearing, the upper support can be held in a simple manner in the target position with regard to the X-direction and the Y-direction.

A particular embodiment of the positioning device, by which in a comparatively simple manner a stable and torsionally stiff supporting of the upper support and also a coupling of this support with the lower support are obtained, is further characterized in that each rod has at its two ends an elastic pivot or hinge having a comparatively low resistance to bending about an axis parallel to the X-direction and a comparatively high resistance to bending about an axis parallel to the Y-direction, while a central part having a comparatively high resistance to bending about axes parallel to the X-direction and the Y-direction is located between the two elastic pivots or hinges.

A further embodiment of the positioning device, which permits comparatively rapid movements of the upper support parallel to the X- and Y-direction, is further characterized in that the first drive for the X-direction comprises a linear electric motor having an X-stator extending parallel to the X-direction and an X-translator displaceable along the stator and secured to the first, upper support, while the X-stator is secured to two Y_1, Y_2-translators which are displaceable parallel to the Y-direction and are guided along Y_1- and Y_2-stators, respectively, extending parallel to the Y-direction, the said second drive for the Y-direction comprising both the Y_1-stator and Y_1-translator constituting a linear electric motor and the Y_2-stator and Y_2-translator also constituting a linear electric motor, said X-translator being displaceable parallel to the Z-direction with respect to the X-stator by means of the actuator and being guided for this purpose along the X-stator by means of rollers displaceable parallel to the Z-direction and rotatable about axes parallel to the Z-direction.

A still further embodiment of the positioning device, by which so-called accumulated tolerances are avoided, is characterized in that the first drive for the X-direction and the second drive for the Y-direction each have at least one translation rod which is displaceable parallel to the relevant coordinate direction (X,Y) and which is coupled by means of a magnetically pre-stressed aerostatic bearing to the first upper

support, the magnetic prestress of the aerostatic bearing being greater than the maximum pulling force occurring between a translation rod and the upper support.

An optical lithographic device for the manufacture of integrated circuits, in which the properties of the positioning device used therein are manifested in a particular manner, is characterized in that an engagement surface for a substrate on the first support is arranged at right angles to an optical axis of a fixedly arranged optical projection lens, which axis coincides with the Z-direction, said optical lithographic device comprising, viewed in the Z-direction, in order of succession the said positioning device and projection lens, a table for a mask that can be translated in the Z-direction and can be rotated about an axis of rotation parallel to the Z-direction, a condenser lens, a diaphragm, a shutter and a light source for repeatedly exposing the substrate.

The invention will be described more fully with reference to the drawings, in which:

Fig. 1 is a diagrammatic sectional elevation of a first embodiment of the positioning device,

Fig. 2 is a perspective view of the positioning device shown in Fig.1,

Fig.3 is a perspective view,partly in section, of a linear electric motor of the kind used in the positioning device shown in Figures 1 and 2,

Fig. 4 is a diagrammatic perspective view of part of supporting and guiding means of the first support as used in the positioning device shown in Figures 1 to 3,

Fig. 5 is an elevation in the Y-direction of a drive used for displacement in the Z-direction in the positioning device shown in Figures 1 to 3,

Fig. 6 is a plan view of the drive shown in Fig.5,

Fig 7 is a block circuit diagram of the servo-controls used for the displacements of the first support in the X-, Y- and Z-directions,

Fig. 8 is a diagrammatic sectional elevation of a second embodiment of the positioning device, and

Fig. 9 is a diagrammatic elevation of an optical lithographic device according to the invention provided with a positioning device according to the invention.

The first embodiment of a positioning device 1 shown in Fig. 1 comprises a horizontally arranged plate-shaped base 3 of, for example, granite. The base 3 is provided with a very smoothly ground horizontal upper surface 5, which is substantially parallel to a lower surface 7. The upper surface 5 can be accurately levelled by means of adjustable feet (not shown) arranged below the lower surface 7. The positioning device comprises an upper first table-shaped support 9 and a lower second support 11, which is constructed as an air foot. The second support 11 is guided and supported with respect to the base 3 by an air film 13. This air film 13 is maintained in a conventional manner by a source of compressed air which for the sake of simplicity is not shown in the drawings. The aerostatic bearing thus obtained is moreover of the pre-stressed type in order to obtain a sufficient stiffness. This is achieved in known manner by connecting a chamber 15 in the second support 11 to a vacuum source (not shown). The first support 9 is coupled to the second support 11 by means of four rods 17 (only two rods 17 are shown in Fig.1) acting as a parallelogram mechanism. With reference to Figures 5 and 6, it will be explained more fully hereinafter how the said parallelogram mechanism can be obtained in a simple manner. When the positioning device is considered to be arranged in a fixed orthogonal coordinate system X,Y,Z, the first support 9 can perform a relative displacement parallel to the Y-direction or Y-axis with respect to the second support 11 with a simultaneous elastic deflection of the rods 17. This displacement can be obtained by means of an actuator 19 secured to the second support. The actuator 19 comprises a direct current motor 21, of which an output shaft is coupled via a reduction 23 to an eccentric 25 shown diagrammatically in Fig.1. The first support 9 is effectively clamped between the eccentric 25 and the free end of a blade spring 27 secured to the second support 11. In the present case, a translator 29 of a linear electric motor, which will be described more fully with reference to Figures 2 and 3, is provided for this purpose on the lower side of the table 9. Therefore, not the first support 9 itself, but the translator 29 secured thereto is clamped between the eccentric 25 and the blade spring 27. The positioning device is intended to cause an object 31 on the first support 9 to be displaced parallel to the X-, Y- and Z-direction. It will appear below that the device is particularly suitable for displacements in the submicron range. In the case in which the object 31 is a semiconductor substrate to be processed (exposed), this substrate can be displaced with great accuracy with respect to an optical axis of an optical system used for repeatedly exposing the substrate. When integrated in a lithographic device, the positioning device can consequently be used in the manufacture of integrated circuits. However, the positioning device is not limited at all to such application.

As can be seen from Fig.2, the translator 29 (designated hereinafter as the"X-translator 29") forms part of an H-shaped system of drives with linear electric motors, which is known per se from the aforementioned magazine "De Constructeur". The positioning device or manipulator described in this magazine, however, is limited to X- and Y-movements. A rotational movement about an axis which is parallel to the Z-axis may be obtained by opposite energization of the linear motors provided for the Y-movements (corresponding to the directions Y_1 and Y_2 parallel to the Y-axis). On the base 3 are arranged four cylindrical

columns 33, to which mounting blocks 35,37 for a Y_1-stator 39 and mounting blocks 41,43 for a Y_2-stator 45 are secured. The mounting block 37 located behind the first support 9 is indicated diagrammatically by a dotted arrow. By means of rollers to be described more fully with reference to Figures 3 and 4, a Y_1-translator 47 is guided along the Y_1-stator 39 and a Y_2-translator 49 is guided along the Y_2-stator 45. The Y_1- and Y_2-translators 47 and 49, respectively, are rigidly connected to a stator 51, along which the X-translator 29 already mentioned above is guided by means of rollers. The stator-translator pairs 39-47, 45-49 and 51-29 constitute the linear electric motors (direct current motors) for the Y_1-, Y_2- and X-movements, respectively, of the first support 9. Although such linear electric motors are known per se, with reference to, inter alia, Figures 3 and 4 a further explanation of their construction will be given because for the Z-movement of the first support 9 use is made of the presence of the air gap between translator and stator in one of these motors, namely, the X-motor. For the sake of simplicity, the explanation will be related to the linear motor for the Y_2-movement, as shown in Fig.3.

In the Y_2-translator 49, which is made of aluminium, there are four pairs of permanent magnets, of which two pairs 53,55 and 57,59 are shown in sectional view only in Fig.3. The magnets 53 and 57 are connected to each other by a soft iron yoke 61, while the magnets 55 and 59 are connected to each other by a soft iron yoke 63. The two magnets 53,55 and 57,59, respectively, of each pair are arranged opposite one another in the wall of the sleeve-like housing of the Y_2-translator 49 and are located above and below an elongate soft iron core 65, around which a series of coaxial coils 67,69 etc. are wound. The magnets 53-59 are magnetized in a direction parallel to the Z-axis. The pair of magnets 53,55 is magnetized in a direction opposite to the direction of magnetization of the pair of magnets 57,59. Successive coils, such as the coils 67,69, are wound in opposite senses. Cylindrical parallel rods 71 and 73 (cf. also Fig.4) are located on either side of the Y_2-stator 45. By means of three rollers 75, 77 and 79, of which the roller 79 is resiliently supported, the Y_2-translator 49 is guided along the rods 71 and 73, which in the neutral position extend paralel to the Y-axis. The Y_2-translator 49 is provided with shafts (not shown), on which the rollers 75, 77 and 79 are journalled. In the neutral position of the first support 9 the Y_2-translator is disposed symmetrically relative to the Y_2-stator 45 so that two air gaps 81 and 83 of the same size (about 400 μm in the direction of the Z-axis) are present above and below the Y_2-stator 45. The X-translator 29 (cf. Figures 2 and 4) is guided in an analogous manner along the X-stator 51 by means of three rollers 85, 87 and 89, of which the roller 89 is resiliently supported. For this purpose, the X-stator 51 is provided with cylindrical parallel rods 91 and 93, which in the neutral position extend parallel to the X-axis. The Y_1-translator 47 is also guided in an analogous manner along the Y_1-stator 39 by means of three rollers 95,97 and 99, of which the roller 99 is resiliently supported. For this purpose, the Y_1-stator 39 is provided with cylindrical parallel rods 101 and 103, which in the neutral position extend parallel to the Y-axis. The rollers 75, 77 and 79 are rotatable about horizontal axis, while the rollers 85,87, 89 and 99 are rotatable about vertical axes. It should be noted that the rollers 95 and 97 are rotatable about axes which enclose an angle of 45° with a horizontal plane at right angles to the Z-axis and which are located in a common vertical plane at right angles to the rods 101 and 103. The roller guides of the three translators not only permit the X-translator 29 to perform a small rotational movement (at most about ± 8 millirad) about an axis of rotation (φ) which is parallel to the Z-axis by energizing the Y_1-motor and the Y_2-motor in opposite senses, but also offer the possibility of displacing the X-translator 29 with respect to the X-stator 51 in a direction parallel to the Z-axis (in the present case over at most about ± 15 μm). In the latter case, the X-stator 51 is also displaced over the same distance with respect to the second support 11 in a direction parallel to the Z-axis. It should be noted that the axis of rotation (φ) coincides with the Z-axis only in the neutral position (cf. Fig.2) of the support 9. In this neutral position, the centre line through the centre of the support 9 also coincides with the Z-axis. In all the remaining positions of the support 9, the axis of rotation (φ) always means an arbitrary line parallel to the Z-axis and perpendicular to the upper surface of the support 9. If it is assumed that the first support 9 is displaced upwards from the neutral position, this means that of the air gaps 81 and 83 also present in the linear X-motor and having the same size the upper air gap 81 is enlarged and the lower air gap 83 is reduced. In the case of the vertical displacements of the first support 9 concerned here over at most about ± 15 μm, the operation of the linear X-motor will not be adversely affected.

As can be seen from Figures 5 and 6, the direct current motor 21 has an output shaft 105 which is coupled via a pair of toothed wheels 107 and 109 in the reduction 23 to a driving shaft 111. The driving shaft 111,supported in ball-bearings 113 and 115, is provided at its end remote from the ball-bearing 113 with an eccentric sleeve 117, which fits with its outer circumference into the inner ring of a ball-bearing 119, whose outer ring fits into a circular hole in a yoke 121. The motor 21 , the reduction 23 and the driving shaft 111 with its ball-bearings 113 and 115 are arranged on a mounting block 123, which is secured on the second support 11 (air foot). A position sensor 125 is secured on the mounting block 123 by means of a bracket 127, which is provided with a slit 129. This slit 129 serves

to clamp the position sensor 125 by means of screw connections 131 in the bracket 127. The position sensor is of the inductive type and is arranged opposite a semi-circular metal vane 133, which is connected to the driving shaft 11. The position sensor 125 is used for the zero point adjustment of the eccentric sleeve 117. Furthermore, the motor 21 is provided with a velocity sensor 126 (tacho). The elastically deformable rods 17 are formed by milling from metal blocks having a height W_1, a width W_2 and a length W_3. The rods 17 each have a comparatively stiff and thick central part 135 and comparatively flexible and thin end portions 137 and 139, which end portions form connections between the centrel part 135 and upper and lower beams 141 and 143, respectively. The two upper beams 141 are secured by means of screw connections (not shown) to the first support 9, while the two lower beams 143 are secured by means of screw connections 145 to the second support 11. The two metal blocks from each of which two rods 17 (cf. Fig.6) with an asssociated upper beam 141 and lower beam 143 are formed, are provided with rectangular apertures 143 having a length W_4 and a height W_5. The rods 17 therefore each have a width which is equal to

$$\frac{W_3 - W_4}{2}$$

This width is sufficient to give the flexible end portions 137 and 139 of the rods 17 acting as elastic pivots or hinges a comparatively high resistance to bending eabout axes parallel to the Y-direction and a comparatively low resistance to bending about axes parallel to the X-direction. The rods 17 are moreover torsionally stiff. The left-hand and right-hand upper beams 141 are clamped between the free end of the blade spring 27 secured in the right-hand lower beam 143 and a projection 149 formed on the yoke 121. The blade spring 27, engaging with pre-stress the right-hand upper beam 141 in the neutral position of the first support 9 and the X-translator 29 ensures a play-free drive. A line connecting the centres of the two end portions 137 and 139 of a rod 17 encloses an acute angle α with a line parallel to the Z-axis (cf. Fig.5). Thus, it is achieved that with a comparatively small displacement parlalel to the Y-direction of the eccentric 25, of which the eccentric sleeve 117 and the ball-bearing 119 forms part, a comparatively large tilting movement of the rods 17 (or flexure of the end portions 137 and 139) and hence a comparatively large displacement of the first support 9 parallel to the Z-direction are obtained. It is assumed that upon energization of the electric motor 21 the first support 9 is held in the relevant X,Y position. This is described more fully hereinafter. In order to give an impression of the displacements concerned, it should be noted that with an eccentricity of 0.2 mm of the sleeve 117 and hence a stroke length of 0.4 mm of the projection 149, a displacement of ± 15 μm of the support 9 parallel to the Z-direction is obtained. The associated values of the angle α are at most 5° 25′ and at least 3° 10′. In the neutral position with regard to the Z-direction, the angle α is equal to 4° 20′ The value of α for this neutral position is determined by the sensitivity which is desired in the mechanical system. Due to the one-piece integral construction of the upper beam 141, lower beam 143 and two rods 17 on each side of the first support 9, a stable torsionally stiff supporting of the support 9 is obtained, which is frictionless, play-free and hysteresis-free. The construction additionally has a high resistance to tilting of the upport 9 about axes parallel to the Y-direction. It should be noted that the central parts 135 of the four rods 17 have a comparatively high resistance to torsion and bending about axes parallel to the X-a nd Y-directions, while the end portions 137 and 139 have a comparatively high resistance to torsion and to bending about axes parallel to the Y-direction.

The electric control of the positioning device will now be described mainly with reference to Figures 2 and 7. The control of the X-, Y_1-, Y_2- and Z-motors is effected by means of four servo systems each comprising a double servo loop. In the said first mode of operation of the Z-actuator constituted by the Z-motor (direct current motor 21) and the eccentric mechanism driven thereby, the first support 9 is displaced in the X- and/or Y-direction, the Z-motor 21 being used only for maintaining the last occupied Z-position. If desired, in the first mode of operation, a rotation (φ) about a vertical axis may also be performed by a particular control of the Y_1- and Y_2-motors. In Fig. 7, the X-, Y_1- and Y_2-motors are denoted by reference numerals 151, 153 and 155, respectively. It has already been described with reference to Figures 2 and 3 how these linear motors are composed. The X- and Y-movements can take place both simultaneously and sequentially. In the said second mode of operation of the Z-actuator, in which the support 9 has reached its target position in the X- and Y-directions, a displacement parallel to the Z-axis is carried out. The support 9 is held for this purpose by means of the three control systems of the X-, Y_1- and Y_2-motors used for the X- and Y-displacements in the X,Y target position. The Z-movement in the second mode of operation therefore never takes place simultaneously with the X- and/or Y-movements, although in a phase which precedes the second mode of operation the X, Y and Z-movements may take place simultaneously. The starting point is the situation in which the support 9 has to be displaced to an X,Y target position in the first mode of operation of the Z-actuator before the support 9 in the second mode of operation of the Z-actuator is displaced to the desired Z-position by means of the Z-actuator. Essentially, it is of course possible to interchange, in terms of time, the first and the second modes of operation. This depends inter alia upon the field of use of the positioning device.

In the circuit diagram of the total control system shown in Fig.7, a so-called position sensor block 157 and a velocity sensor block 159 are provided. The block 157 represents the X-, Y_1-, Y_2- and Z-position sensors, while the block 159 represents the X-, Y_1-,, Y_2- and Z-velocity sensors. The signals originating from the position sensors and from the velocity sensors, respectively, are indicated in Fig.7 by X, Y_1, Y_2, Z and by $\dot{X}$, $\dot{Y}_1$, $\dot{Y}_2$ and $\dot{Z}$, respectively. All sensors are of a type known per se. The X-, Y_1- and Y_2-position sensors are laser interferometers, which utilize the same laser beam 161 (cf. Fig.2). The laser beam 161 is split up by means of beam splitters 163 and 165 into a sub-beam 167 for the X-sensor and sub-beams 169 and 171 for the Y_1-sensor and the Y_2-sensor, respectively. The sub-beam 167 is split up by means of a semi-transparent prism 173 into a reference beam (not shown) and an X-measuring beam 175. The measuring beam 175 is reflected by a side of the support 9 in the form of a mirror. The reflected measuring beam 175 interferes with the reference beam reflected on a reference mirror (not shown). The intensity of an interference beam 177 thus produced is measured by a photocell in a receiver 179. The X-signal supplied by the receiver is a measure of the displacement of the support 9 parallel to the X-axis. The displacement parallel to the Y-axis is measured in a similar manner, but at two area of the relevant side of the support 9 in the form of a mirror. The Y_1-signal is supplied by an arrangement comprising a semi-transparent prism 181 of the same type as the prism 173 and a receiver 183, while the Y_2-signal is supplied by an arrangement comprising a semi-transparent prism 185 of the same type as the prism 173 and a receiver 187. The Y_1- and Y_2-measuring beams are indicated in Fig. 2 by reference numerals 189 and 191, respectively, while the Y_1 - and Y_2-interference beams are indicated by reference numerals 193 and 195, respectively. It should be noted that the measurement for the displacement parallel to the Y-axis is carried out at two areas in order that also a signal can be derived therefrom which is a measure of the rotational movement φ about an axis parallel to the Z-axis. When the sum of the Y_1- and Y_2- signals is halved, an average accurate signal of the Y-displacement is obtained, while, when the difference between the Y_1- and Y_2-signals is divided by a factor A (cf. Fig.7), an accurate signal of the φ rotationalmovement is obtained. The factor A takes into account the influence of the fact that there is measured at two areas of a side of the support 9, which are located at a considerable distance from the point of application of the driving Lorentz forces to the Y_1-translator 47 and the Y_2-translator 49 (cf. Fig.2). The $\dot{X}$-velocity signal is derived by differentiation from the X-position signal by means of a differentiator 197 (cf. Fig.7). The $\dot{Y}_1$- and $\dot{Y}_2$-velocity signals are obtained by means of known velocity sensors (tacho's), which are therefore not shown and which are coupled with the guide rollers of the Y_1-translator 47 and the Y_2-translator 49. The Z-position signal is obtained by means of an optical detection device indicated diagrammatically in Fig. 2 by reference numeral 199 and known per se from US-PS 4,356,392. It should be noted that the Z-signal may also be obtained by measuring the relative horizontal displacement between the first support 9 and the second support 11 by means of feelers on the two supports and by recalculating the measuring signals of these feelers into a Z-signal. Both sensor types may also be used for the Z-signal and the last-mentioned type may then be used for the zero point adjustment of the optical detection device. The $\dot{Z}$-velocity signal is obtained by means of the speed sensor 126 (tacho) already described with reference to Figures 5 and 6.

As can be seen from Fig. 7, the X-signal is supplied to a comparator 201, which receives a reference signal X_{ref} from a processor 203, for example a microprocessor. The comparator 201 supplies a difference signal to a PI controller 205, which prevents oscillations from being produced in the control loop. The output signal of the proportional integrating controller 205 is supplied to a comparator 207, which receives both the $\dot{X}$-signal and a reference signal $\dot{X}_{ref}$ from the processor 203. Through a P controller 209, the output signal of the comparator 207 is supplied to the X-motor 151. The double control loop or combined position velocity loop for a controlling the X-displacement described herein is of a type known per se, for example, from the aforementioned magazine "De Constructeur". The velocity loop integrated in the position loop is used inter alia to reach the target position without overshoot. The control thus becomes more rapid. The Y_1- and Y_2-signals are converted in a combined summation/subtraction circuit 211 into two output signals. One output signal

$$\frac{(Y_1 + Y_2)}{2}$$

of the circuit 211 represents the displacement of the support 9 parallel to the Y-axis, while the other output signal $(Y_1-Y_2)/A)$ is a measure of the rotational movement (φ) about an axis parallel to the Z-axis. The signal proportional to the Y-displacement $(Y_1+Y_2)/2)$ is supplied to a comparator 213, which also receives a reference signal Y_{ref} from the processor 203. The comparator 213 supplies a difference signal ΔY to a PI controller 215, which is connected to an adder 217 and a subtractor 219 in a combined summation/subtraction circuit 221. The signal proportional to the φ rotational movement $(Y_1-Y_2)/A)$ is supplied to a comparator 223, which also receives a reference signal φ_{ref} from the processor 203. The comparator 223 supplies a difference signal $\Delta\varphi$ to a PI controller 225, which is also connected to the adder 217 and the subtractor 219 in the circuit 221. If no rotational movement (φ) is desired, $\Delta\varphi$ is equal to zero and the circuit

221 supplies two equal signals Δ Y. The Y_1- and Y_2-motors then run at the same speed and in the same direction. If on the contrary a rotational movement (φ) is desired, the circuit supplies an output signal ΔY+Δφ and an output signal ΔY-Δφ. The Y_1- and Y_2-motors now run with a different speed in the same direction or at the same speed in opposite directions. The output signal ΔY+Δφ corresponding to the Y_1-motor is supplied to a comparator 227, which also receives a reference signal $\dot{Y}_{1ref}$ from the processor 203 and a velocity signal $\dot{Y}$ from the Y_1-velocity sensor. Via a P controller 229, the difference signal of the comparator 227 is supplied to the Y_1-motor 153. The output signalΔ Y-Δφ corresponding to the Y_2-motor is supplied to a comparator 231, which also receives a reference signal $\dot{Y}_{2ref}$ from the processor 203 and a velocity signal $\dot{Y}_2$ from the Y_2-velocity sensor. Via a P controller 233, the difference signal of the comparator 231 is supplied to the Y_2-motor 155. The Z-signal is supplied to a comparator 235, which receives a reference signal Z_{ref} from the processor 203. The comparator 235 supplies a difference signal to a PI controller 237. The output signal of the PI controller 237 is supplied to a comparator 239, which receives both the $\dot{Z}$-signal and the reference signal $\dot{Z}_{ref}$ from the processor 203. Via a P controller 241, the output signal of the comparator 239 is supplied to the Z-motor 21.

During the X-, Y-movements, the Z-position of the support 9 has to be maintained to the optimum. This is effected by holding the last-sensed Z-position and supplying it to the comparator 235, while the Z-position sensor (the optical detection device) is decoupled from the comparator 235 as long as the X,Y target position has not yet been reached. When, for example, a capacitor 243 and a switch 245 controlled by the processor 203 is included in the connection between the Z-position sensor and the comparator 235, this object may be achieved. Conversely, during the Z-movement the X,Y target position of the support 9 has to be maintained to the optimum. This is effected in the same manner as described above for the Z-position. For the sake of brevity, this is not indicated further in Fig.7.

The second embodiment of the positioning device shown in Fig.8 is provided as far as possible with reference numerals corresponding to those of the first embodiment. The difference from the first embodiment resides in the different drives for the X- and Y-driections. The drive for the Z-direction is the same as described above with reference to Figures 5 and 6. The electric control of the X-, Y- and Z-drives is of the same type as described above with reference to Fig. 7. Fig. 8 only shows the drive for the Y-direction; that for the X-direction is identical thereto. If desired, an Y_1- as well as an Y_2-drive may be chosen. In this case, a rotational movement (φ) of the support 9 about a vertical axis is possible in the manner described for the first embodiment. The Y-drive shown in Fig. 8 (and hence also the X-drive) is denoted by reference numeral 247. This drive is of a type proposed and described already in Netherlands Patent Application 8500930 and comprises a translation rod 249, which is displaceable, for exmaple, by means of a friction transmission and is secured by means of an elastically deformable coupling member 251 to a block 253. The block 253 has secured to it a box 255 of a magnetically poorly conducting material, which accommodates three permanent magnets 257, 259 and 261, which are separated from each other by magnetically conducting yokes 263, 265, 267 and 269. The support 9 has secured to it a plate 271 of magnetically conducting material. The block 253 is provided with a supply duct 273 for compressed air, which duct opens into an air gap between the drive 247 and the plate 271. The aerostatic coupling (bearing) thus obtained is pre-stressed by the permanent magnets 257, 259 and 261, magnetized parallel to the Z-axis with a force exceeding the maximum pulling force occurring during operation between the drive 247 and the support 9. A particular advantage of the drive described is that a frictionless coupling is obtained between the driving element and the driven element. With respect to the first embodiment of the positioning device, the displacement in the Z-direction can be comparatively large because it is not limited by the permissible variation of the air gap in a linear motor. The possible displacement in the Z-direction is now mainly determined by the parallelogram mechanism of the rods 17.

The two embodiments of the positioning device according to the invention described above are very suitable for use in an optical lithographic device 275 according to the invention shown in Fig.9, due to their frictionless, play-free and hysteresis-free construction. The device 275 shown in Fig.9 is used in the manufacture of integrated circuits and in fact constitutes a repeating optical projection system whose piéce de résistance is the support 9, by which an object 31 (semiconductor substrate) can be positioned in the X-, Y-, Z- and, if desired, φ-directions. The columns 33 (cf. Fig.2) not shown in Fig.9 are mounted on the upper surface 5 of the granite plate 3. Fig.9 shows the use of the first embodiment of the positioning device in the optical lithographic device 275. With the use of the second embodiment described with reference to Fig.8, the drive of the translation rod 247 is of course mounted on the granite plate 3. In the optical lithographic device 275, a projection lens 277 is provided, which is fixedly arranged with its lens holder in an objective plate 279. This objective plate 279 forms part of a frame 281. The granite plate 3 and an upper plate 283 also form part of the frame 281. The plate 3, extending in a horizontal plane at right angles to the Z-axis, is arranged on adjustable support members 285. The frame 281 is arranged so that the opt-

ical axis of the projection lens 277 coincides with the Z-axis. The equipment is further provided with a so-called Z-Θ manipulator 287, which is proposed and described in Netherlands Patent Application 8600785. The manipulator 287 has an engagement member for a mark 289, which can be displaced parallel to the Z-axis with respect to the projection lens 277 and can be rotated about an axis of rotation Θ coinciding with the Z-axis and the optical axis of the projection lens 277. The repeated exposure of the substrate 31 situated on the support 9 takes place in a number of different X,Y target positions of the support 9 with respect to the projection lens 277. For positioning the support 9 in the X,Y target positions, the interferometer system already described with reference to Fig. 2 is used. In each X,Y target position, the adjustment of the support 9 already explained then takes place parallel to the Z-axis. It should be noted that any φ-adjustment of the support 9 may take place before or after the X,Y target positions are reached. Above the plate 283 a light source 291 with a parabolic reflector 293 is arranged. Via a mirror 295, a shutter 296, a diaphragm section 297, a mirror 299 and a condenser lens 301, the light is conducted to the mask 289. By means of the projection lens 277, the mask 289 is imaged on the substrate 31. The image of the mask 289 is focused on thesubtrate 31 by means of the optical detection device 199, known per se (cf. USP 4,356,392), which supplies the aforementioned Z-signal to the control system described with reference to Fig.7. Both the mask 289 and the substrate 31 are provided with two alignment markers with, for example, X,Y gratings. These alignment markers serve to register or align the mask with respect to the substrate, use being made of an alignment system 303 already proposed and described in Netherlands Patent Application 8600639. The alignment system 303 detects when the projection of the alignment markers on the mask and on the substrate cover each other in projection, while the interferometer system for the X,Y target position (cf Fig.2) determines the extent of the horizontal displacements of the support 9 that were required thereto. From these data are calculated both the required angle ΔΘ for alignment of the mask with respect to the substrate and the value of the relative translational movement parallel to the Z-axis of the mask and the lens required to obtain a correction enlargement. By means of the Z-Θ manipulator 287, the mask 289 is then rotated with respect to the substrate about the axis of rotation Θ (coincides with the Z-axis and also with the axis of rotation φ of the positioning device 1) and is translated parallel to the Z-axis until a perfect registration and a correct enlargement are obtained. Due to the fact that the positioning device according to the invention permits displacements as far as in the submicron range, it is particularly suitable for optical lithographic devices, in which such displacements are necessary.

The positioning device can generally be used for frictionless, play-free and hysteresis-free displacements of materials and objects to be examined and/or to be processed. In many cases, manipulations are then required in the X-, Y-, Z- and, if desired, the φ-directions. It should be noted that the φ-rotation described is not always required and that translational movements in the X-, Y- and Z-directions may be sufficient. In these cases, the Y_2-motors and drives are superfluous. Such positioning device also lie within the scope of the invention.

In the above description, the term "parallelogram mechanism" has been used with regard to the rods 17. Although the rods 17 described are locally elastically deflexible at the area of the elastic pivots or hinges, blade springs or fully circular rods may also be employed. Such rods are also considered to be within the scope of term "parallelogram mechanism". In principle, the term "parallelogram mechanism" is used when parallel rod-shaped connecting members between two bodies permit a displacement parlalel to itself of one of these bodies by at least partial elastic flexure of the connecting members.

Claims

1. A positioning device (1) comprising a first, upper and a second, lower support (9, 11) which are coupled to each other by means of at least two elastically deflexible rods (17) acting together as a parallelogram mechanism, said first, upper support (9) being displaceable with respect to a base (3) of the device (1) in directions parallel to coordinate directions X and Y of an orthogonal coordinate system X, Y, Z, said first, upper support (9) further being displaceable with respect to said second, lower support (11) in a direction parallel to the Z-direction by means of a Z-actuator (19), characterized in that the Z-actuator (19) comprises an electric motor (21) of which a driving shaft (111) is coupled to an eccentric (25) by means of which the lower support (11) is displaceable with respect to the upper support (9) in a direction parallel to one of the coordinate directions X or Y, said relative displacement of said supports (9, 11) effecting simultaneous elastic deflection of said rods (17), said deflection effecting displacement of the upper support (9) with respect to the lower support (11) in a direction parallel to the Z-direction, and in that the lower support (11) is guided and supported with respect to the base (3) by means of a static bearing (15) which is prestressed in the Z-direction and which comprises a viscous carrier medium (13).

2. A positioning device (1) as claimed in Claim 1, characterized in that each rod (17) has at its two

ends an elastic pivot or hinge (137, 139) having a comparatively low resistance to bending about an axis parallel to the X-direction and a comparatively high resistance to bending about an axis parallel to the Y-direction, while a central part (135) having a comparatively high resistance to bending about axes parallel to the X-direction and the Y-direction is located between the two elastic pivots or hinges (137, 139).

3. A positioning device (1) as claimed in Claim 1, characterized in that a first drive for the X-direction comprises a linear electric motor having an X-stator (51) extending parallel to the X-direction and an X-translator (29) displaceable along the X-stator (51) and secured to the first, upper support (9), while the X-stator (51) is secured to two Y_1, Y_2-translators (47, 49) which are displaceable parallel to the Y-direction and are guided along Y_1- and Y_2-stators (39, 45), respectively, extending parallel to the Y-direction, a second drive for the Y-direction comprising both the Y_1-stator (39) and Y_1-translator (47) constituting a linear electric motor and the Y_2-stator (45) and Y_2-translator (49) also constituting a linear electric motor, said X-translator (29) being displaceable parallel to the Z-direction with respect to the X-stator (51) by means of the actuator (19) and being guided for this purpose along the X-stator (51) by means of rollers (85, 87, 89) displaceable parallel to the Z-direction and rotatable about axes parallel to the Z-direction.

4. A positioning device (1) as claimed in Claim 1, characterized in that a first drive for the X-direction and a second drive (247) for the Y-direction each have at least one translation rod (249) which is displaceable parallel to the relevant coordinate direction (X, Y) and which is coupled by means of a magnetically pre-stressed aerostatic bearing (257, 259, 261, 273) to the first, upper support (9), the magnetic pre-stress of the aerostatic bearing (257, 259, 261, 273) being greater than the maximum pulling force occurring between the translation rod (249) and the upper support (9).

5. An optical lithographic device (275) for the manufacture of integrated circuits provided with a positioning device (1) as claimed in Claim 1, wherein an engagement surface for a substrate (31) on the first support (9) is arranged at right angles to an optical axis of a fixedly arranged optical projection lens (277), which axis coincides with the Z-direction, said optical lithographic device (275) comprising, viewed in the Z-direction, in order of succession the said positioning device (1) and projection lens (277), a table (287) for a mask (289) that can be translated in the Z-direction and can be rotated about an axis of rotation parallel to the Z-direction, a condenser lens (301), a diaphragm (297), a shutter (296) and a light source (291) for repeatedly exposing the substrate (31).

Patentansprüche

1. Positioniervorrichtung (1) mit einer ersten, oberen und einer zweiten, unteren Tragvorrichtung (9, 11), die mittels mindestens zweier elastisch umlenkbarer Stäbe (17), die gemeinsam als ein Parallelogrammechanismus wirken, miteinander gekoppelt sind, wobei diese erste obere Tragvorrichtung (9) in Richtungen parallel zu Koordinatenrichtungen X und Y eines orthogonalen Koordinatensystems X, Y, Z gegenüber einer Grundplatte (3) der Vorrichtung (1) verschiebbar ist und wobei diese erste obere Tragvorrichtung (9) ferner mittels eines Z-Stellglieds (19) in einer Richtung parallel zur Z-Richtung gegenüber obiger zweiten, unteren Tragvorrichtung (11) verschiebbar ist, dadurch gekennzeichnet, daß das Z-Stellglied (19) einen Elektromotor (21) enthält, dessen Abtriebswelle (111) mit einem Exzenter (25) gekoppelt ist, durch den die untere Tragvorrichtung (11) in einer Richtung parallel zu einer der Koordinatenrichtungen X oder Y zur oberen Tragvorrichtung (9) verschiebbar ist, wobei diese Relativbewegung dieser Tragvorrichtungen (9, 11) eine gleichzeitige elastische Umlenkung obiger Stäbe (17) und diese Umlenkung ihrerseits eine Verschiebung der oberen Tragvorrichtung (9) zur unteren Tragvorrichtung (11) in einer Richtung parallel zur Z-Richtung bewirkt, und daß die untere Tragvorrichtung (11) mittels eines in Z-Richtung vorgespannten und ein viskoses Tragmedium (13) enthaltenden statischen Lagers (15) zur Grundplatte (3) geführt und getragen wird.

2. Positioniervorrichtung (1) nach Anspruch 1, dadurch gekennzeichnet, daß jeder Stab (17) an beiden Enden ein elastisches Gelenk oder Scharnier (137, 139) mit vergleichsweise niedrigem Widerstand gegen Biegung um eine Achse parallel zur X-Richtung und vergleichsweise hohem Widerstand gegen Biegung um eine Achse parallel zur Y-Richtung aufweist, wobei zwischen den beiden elastischen Gelenken oder Scharnieren (137, 139) ein Mittelteil (137) mit vergleichsweise hohem Widerstand gegen Biegung um Achsen parallel zur X-Richtung und zur Y-Richtung angeordnet ist.

3. Positioniervorrichtung (1) nach Anspruch 1, dadurch gekennzeichnet, daß ein erster Antrieb für die X-Richtung einen elektrischen Linearmotor

mit einem parallel zur X-Richtung liegenden X-Ständer (51) und einem am X-Ständer (51) entlang beweglichen und an der ersten, oberen Tragvorrichtung (9) befestigen X-Läufer (29) aufweist, während der X-Ständer (51) an zwei parallel zur Y-Richtung beweglichen und jeweils an den parallel zur Y-Richtung liegenden Y_1- und Y_2-Ständern (39, 45) entlanggeführten Y_1-, Y_2-Läufern (47, 49) befestigt ist, wobei ein zweiter Antrieb für die Y-Richtung sowohl den Y_1-Ständer (39) und den Y_1-Läufer (47), die einen elektrischen Linearmotor bilden, als auch den Y_2-Ständer (45) und den Y_2-Läufer (49), die gleichfalls einen elektrischen Linearmotor bilden, umfaßt, während obiger X-Läufer (29) mittels des Stellglieds (19) parallel zur Z-Richtung relativ zum X-Ständer (51) beweglich ist und hierzu mittels parallel zur Z-Richtung beweglicher und um Achsen parallel zur Z-Richtung drehbarer Rollen (85, 87, 89) am X-Ständer (51) entlanggeführt wird.

4. Positioniervorrichtung (1) nach Anspruch 1, dadurch gekennzeichnet, daß sowohl ein erster Antrieb für die X-Richtung als auch ein zweiter Antrieb (247) für die Y-Richtung mindestens eine parallel zur jeweiligen Koordinatenrichtung (X, Y) verschiebbare und mittels eines magnetisch vorgespannten aerostatischen Lagers (257, 259, 261, 273) mit der ersten, oberen Tragvorrichtung (9) gekoppelte Schubstange (249) aufweist, wobei die magnetische Vorspannung des aerostatischen Lagers (257, 259, 261, 273) größer ist als die maximale zwischen der Schubstange (249) und der oberen Tragvorrichtung (9) auftretende Zugkraft.

5. Mit einer Positioniervorrichtung (1) nach Anspruch 1 versehene optolithographische Vorrichtung (275) zur Herstellung von integrierten Schaltungen, in der eine Haltefläche für ein Substrat (31) auf der ersten Tragvorrichtung (9) rechtwinklig zu einer optischen Achse einer starr angeordneten optischen Projektionslinse (277) angeordnet ist, welche Achse mit der Z-Richtung übereinstimmt, wobei diese optolithographische Vorrichtung (275), in der Reihenfolge obiger Positioniervorrichtung (1) und Projektionslinse (277) in Z-Richtung gesehen, einen in Z-Richtung verschiebbaren und um eine Drehachse parallel zur Z-Richtung drehbaren Tisch (287) für eine Maske (289), eine Sammlerlinse (301), eine Blende (297), einen Verschluß (296) und eine Lichtquelle (291) zur repetierenden Belichtung des Substrats (31) umfaßt.

Revendications

1. Dispositif de positionnement (1) comprenant un premier support supérieur (9) et un deuxième support inférieur (11) qui sont accouplés l'un à l'autre à l'aide d'au moins deux tiges fléxibles de manière élastique (17) agissant ensemble comme un mécanisme à parallélogramme déformable, ledit premier support supérieur (9) pouvant se déplacer par rapport à une base (3) du dispositif (1) dans des directions parallèles aux directions de coordonnées X et Y d'un système de coordonnées orthogonales X, Y, Z, ledit premier support supérieur (9) pouvant, en outre, se déplacer par rapport audit deuxième support inférieur (11) dans une direction parallèle à la direction Z à l'aide d'un actionneur Z (19), caractérisé en ce que l'actionneur Z (19) comprend un moteur électrique (21) dont un arbre d'entraînement (111) est accouplé à une excentrique (25) à l'aide duquel le support inférieur (11) peut être déplacé par rapport au support supérieur (9) dans une direction parallèle à l'une des directions de coordonnées X ou Y, ledit déplacement relatif desdits supports (9, 11) assurant une flexion élastique simultanée desdites tiges (17), ladite flexion effectuant le déplacement du support supérieur (9) par rapport au support inférieur (11) dans une direction parallèle à la direction Z, et en ce que le support inférieur (11) est guidé et supporté par rapport à la base (3) à l'aide d'un palier statique (15) qui est précontraint dans la direction Z et qui comprend un milieu de support visqueux (13).

2. Dispositif de positionnement (1) selon la revendication 1, caractérisé par ailleurs en ce que chaque tige (17) a, à ses deux extrémités, un pivot ou une charnière élastique (137, 139) ayant une résistance relativement faible à la flexion autour d'un axe parallèle à la direction X et une résistance relativement élevée à la flexion autour d'un axe parallèle à la direction Y, tandis qu'une partie centrale (135) ayant une résistance relativement élevée à la flexion autour d'axes parallèles à la direction X et à la direction Y est disposée entre les deux pivots ou charnières élastiques (137, 139).

3. Dispositif de positionnement (1) selon la revendication 1, caractérisé en ce qu'un premier entraînement pour la direction X comprend un moteur électrique linéaire ayant un stator X (51) s'étendant parallèlement à la direction X et un translateur X (29) déplaçable le long du stator X (51) et fixé au premier support supérieur (9), tandis que le stator X (51) est fixé aux deux translateurs Y_1, Y_2 (47, 49) qui sont déplaçables parallèlement à la direction Y et sont guidés le long de stators Y_1 et Y_2 (39, 45), respectivement, s'étendant paral-

lèlement à la direction Y, un deuxième entraînement pour la direction Y comprenant à la fois le stator Y_1 (39) et le translateur Y_1 (47) constituant un moteur électrique linéaire et le stator Y_2 (45) et le translateur Y_2 (49) constituant également un moteur électrique linéaire, ledit translateur X (29) pouvant être déplacé parallèlement à la direction Z par rapport au stator X (51) à l'aide de l'actionneur (19) et étant guidé à cet effet le long du stator X (51) à l'aide de galets (85, 87, 89) déplaçables parallèlement à la direction Z et susceptibles de tourner autour d'axes parallèles à la direction Z.

4. Dispositif de positionnement (1) selon la revendication 1, caractérisé en ce qu'un premier entraînement pour la direction X et un deuxième entraînement (247) pour la direction Y ont chacun au moins une tige de translation (249) qui est déplaçable parallèlement à la direction de coordonnée concernée (X, Y) et qui est accouplée à l'aide d'un palier aérostatique (257, 259, 261, 273) précontraint magnétiquement au premier support supérieur (9), la précontrainte magnétique du palier aérostatique (257, 259, 261, 273) étant supérieure à la force de traction maximum qui s'exerce entre une tige de translation (249) et le support supérieur (9).

5. Dispositif lithographique optique (275) pour la fabrication de circuits intégrés, pourvu d'un dispositif de positionnement (1) selon la revendication 1, dans lequel une surface d'engagement pour un substrat (31) sur le premier support (9) est agencée perpendiculairement à un axe optique d'une optique de projection (277) montée fixe, ledit axe coïncidant avec la direction Z, ledit dispositif lithographique optique (275) comprenant, vu dans la direction Z, dans l'ordre de succession, ledit dispositif de positionnement (1) et l'optique de projection (277), une table (287) pour un masque (289) qui peut être soumise à une translation dans la direction Z et à une rotation autour d'un axe de rotation parallèle à la direction Z, un condensateur (301), un diaphragme (297), un obturateur (296) et une source de lumière (291) pour exposer le substrat (31) de manière répétée.

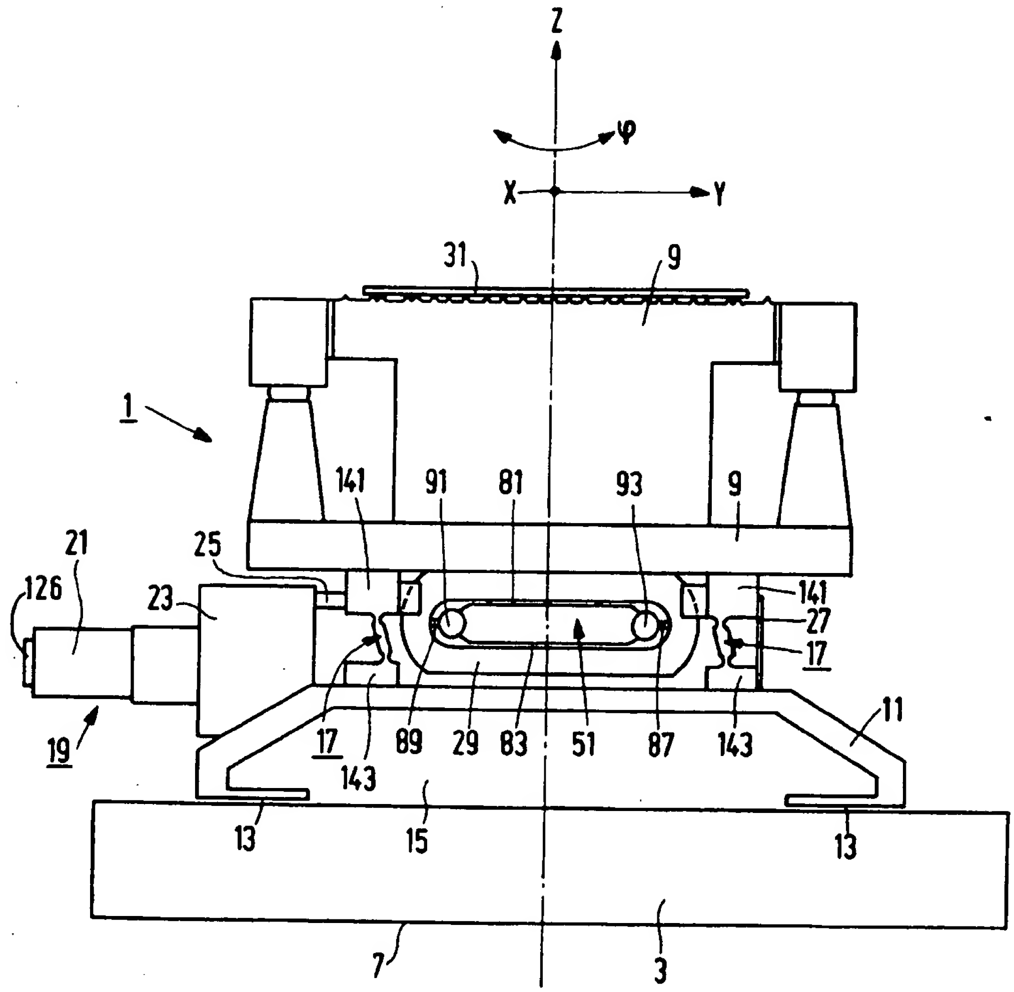
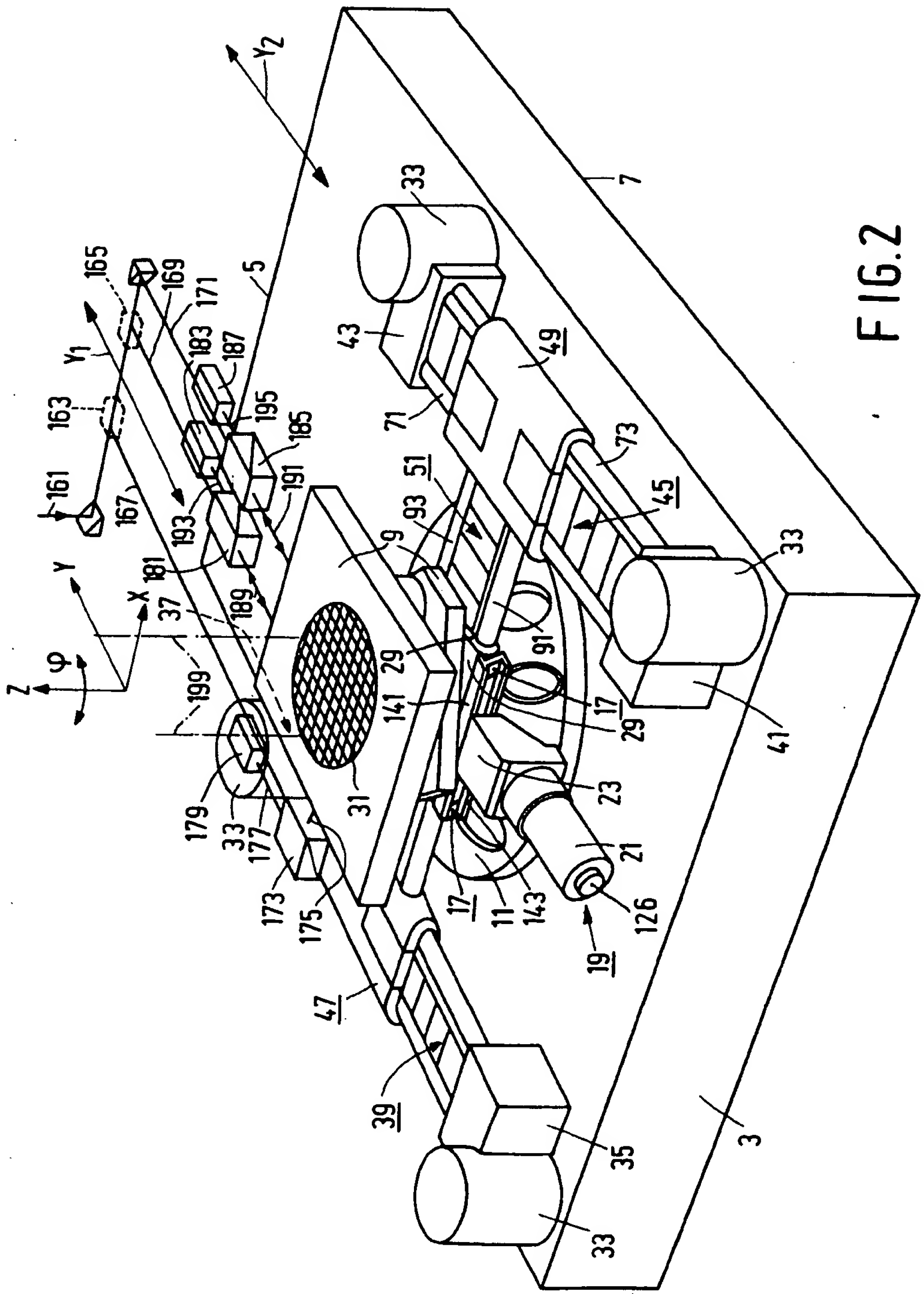

Z
φ
X
Y
31
9
1
141
91
81
93
9
21
25
126
23
141
27
17
11
19
17
143
89
29
83
51
87
143
143
13
15
13
7
3

FIG.1


Y2
7
5
33
165
169
171
Y1
183
187
163
195
185
161
167
193
191
43
49
71
73
45
51
93
9
Y
X
181
37
189
Z
φ
199
91
29
141
17
29
41
33
179
33
177
173
175
31
23
21
17
11
143
126
19
47
39
35
33
3

F IG.2

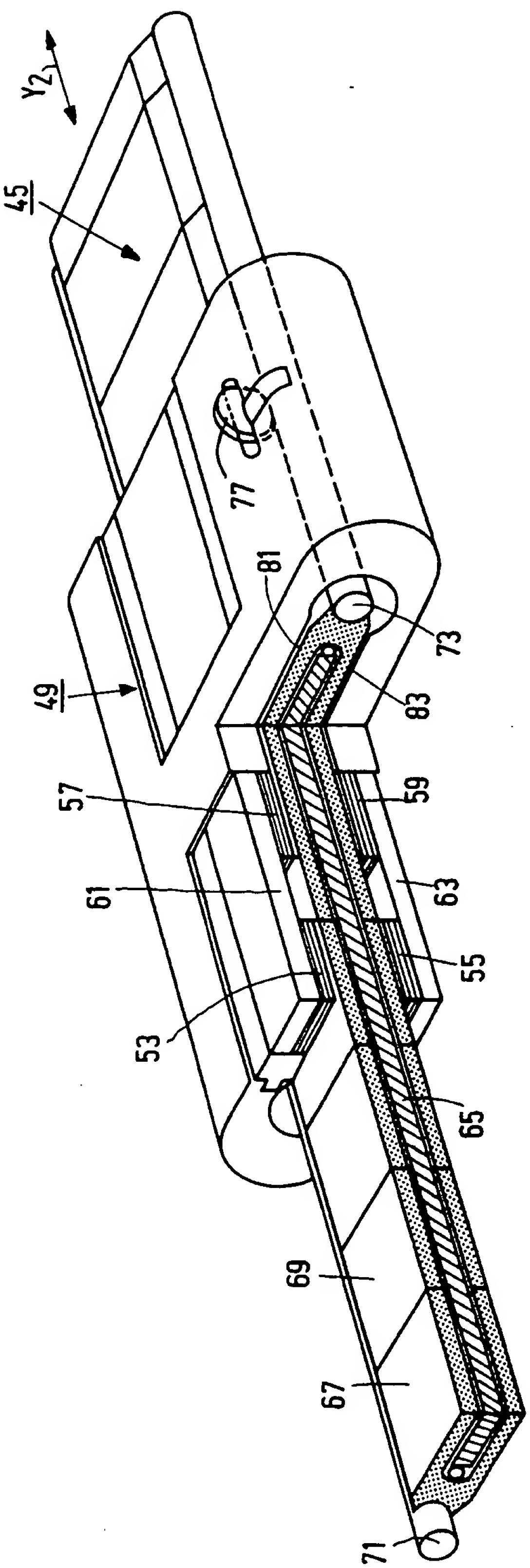


FIG.3

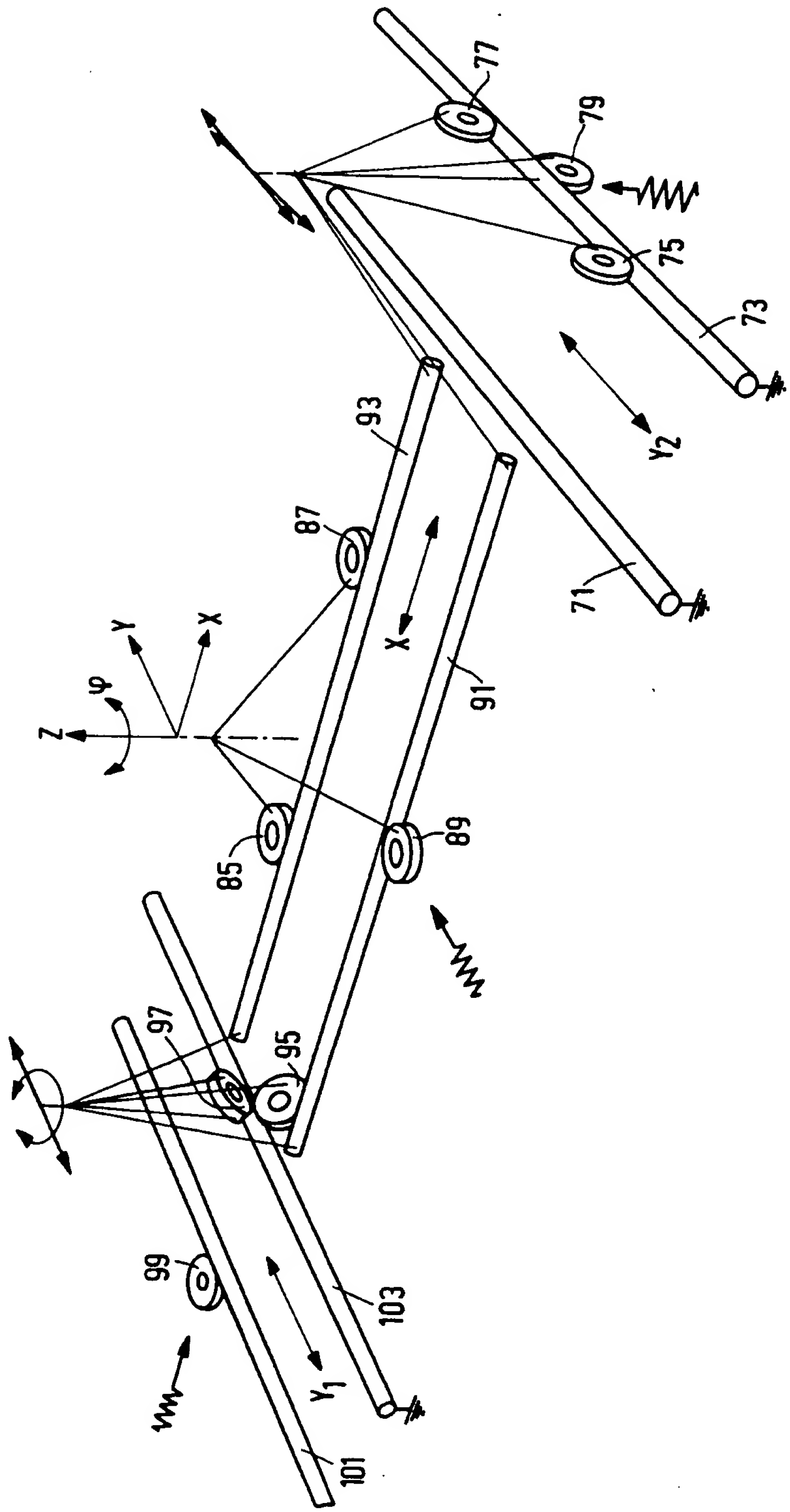
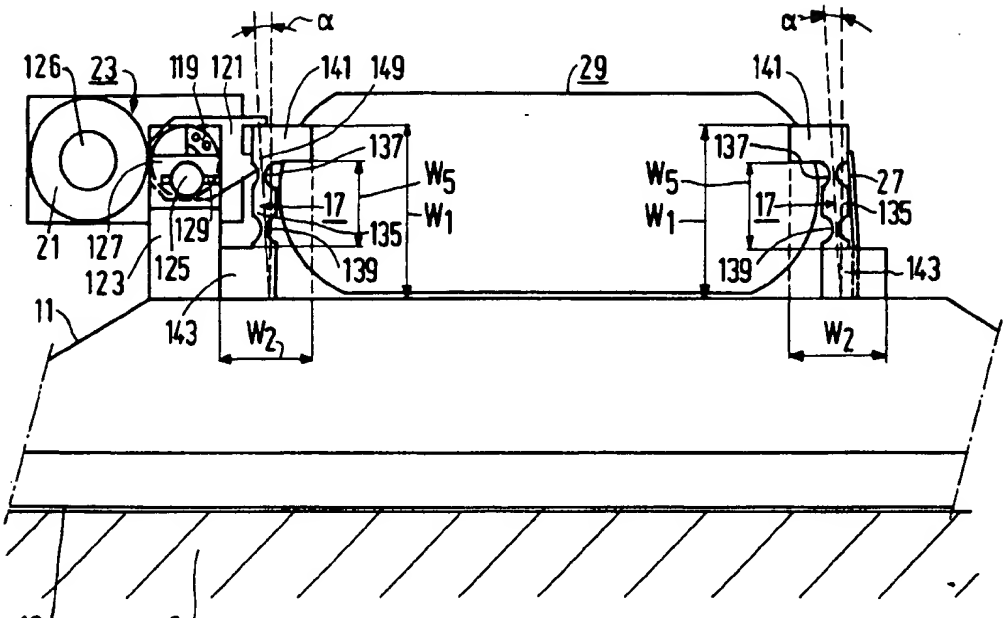


FIG.4


α
α
126
23
119
121
141
149
29
141
137
W5
W1
17
135
139
137
W5
W1
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135
139
143
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127
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125
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143
W2
W2
11
13
3

FIG.5

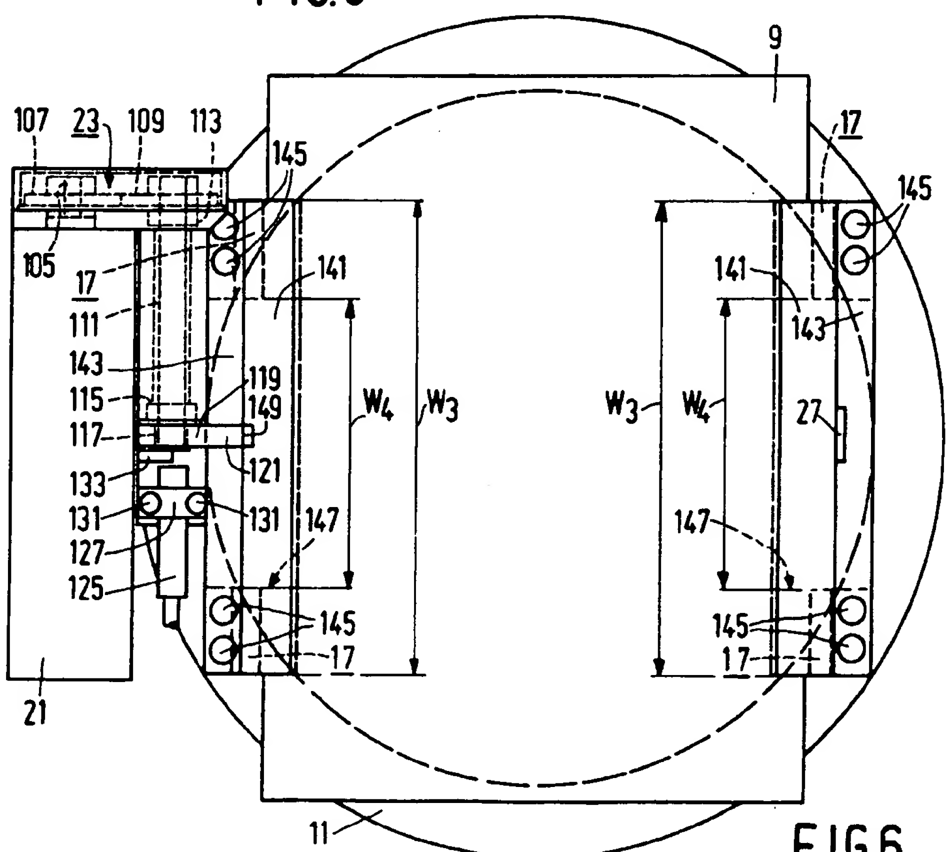

9
107
23
109
113
145
17
145
105
17
111
141
141
143
143
119
149
115
117
W4
W3
W3
W4
27
121
133
131
131
147
147
127
125
145
17
145
17
21
11

FIG.6

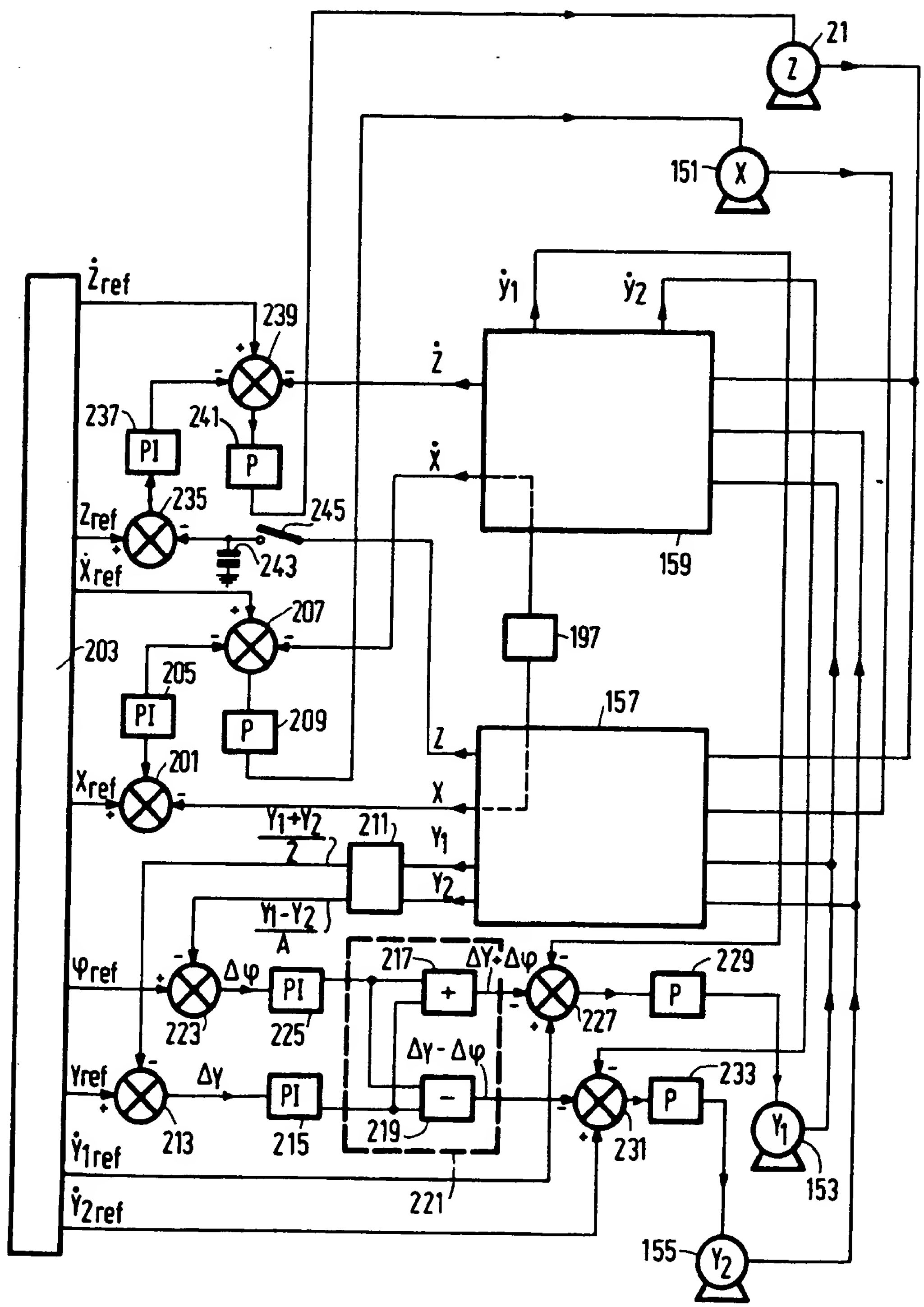

21
Z
151
X
$\dot{y}_1$
$\dot{y}_2$
$\dot{Z}_{ref}$
239
$\dot{Z}$
237
241
PI
P
$\dot{X}$
235
245
Z_{ref}
243
159
$\dot{X}_{ref}$
207
197
203
205
PI
P
209
157
201
Z
X_{ref}
X
$\frac{Y_1+Y_2}{2}$
211
Y_1
Y_2
$\frac{Y_1-Y_2}{A}$
217
$\Delta Y+\Delta\varphi$
229
φ_{ref}
$\Delta\varphi$
PI
+
P
223
225
227
$\Delta Y-\Delta\varphi$
Y_{ref}
ΔY
PI
−
P
233
215
219
231
213
Y_1
$\dot{Y}_{1ref}$
153
221
$\dot{Y}_{2ref}$
155
Y_2

FIG.7

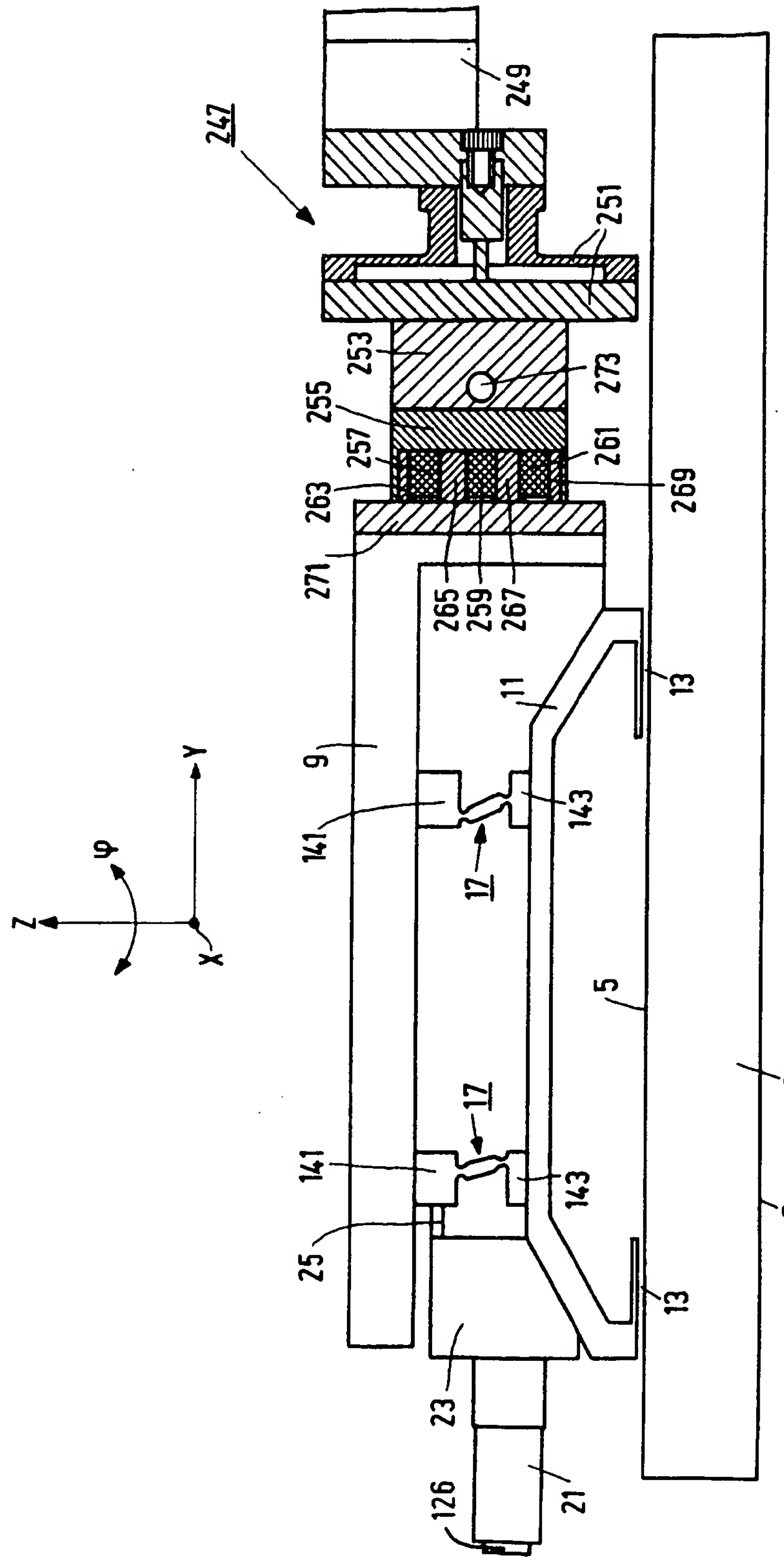
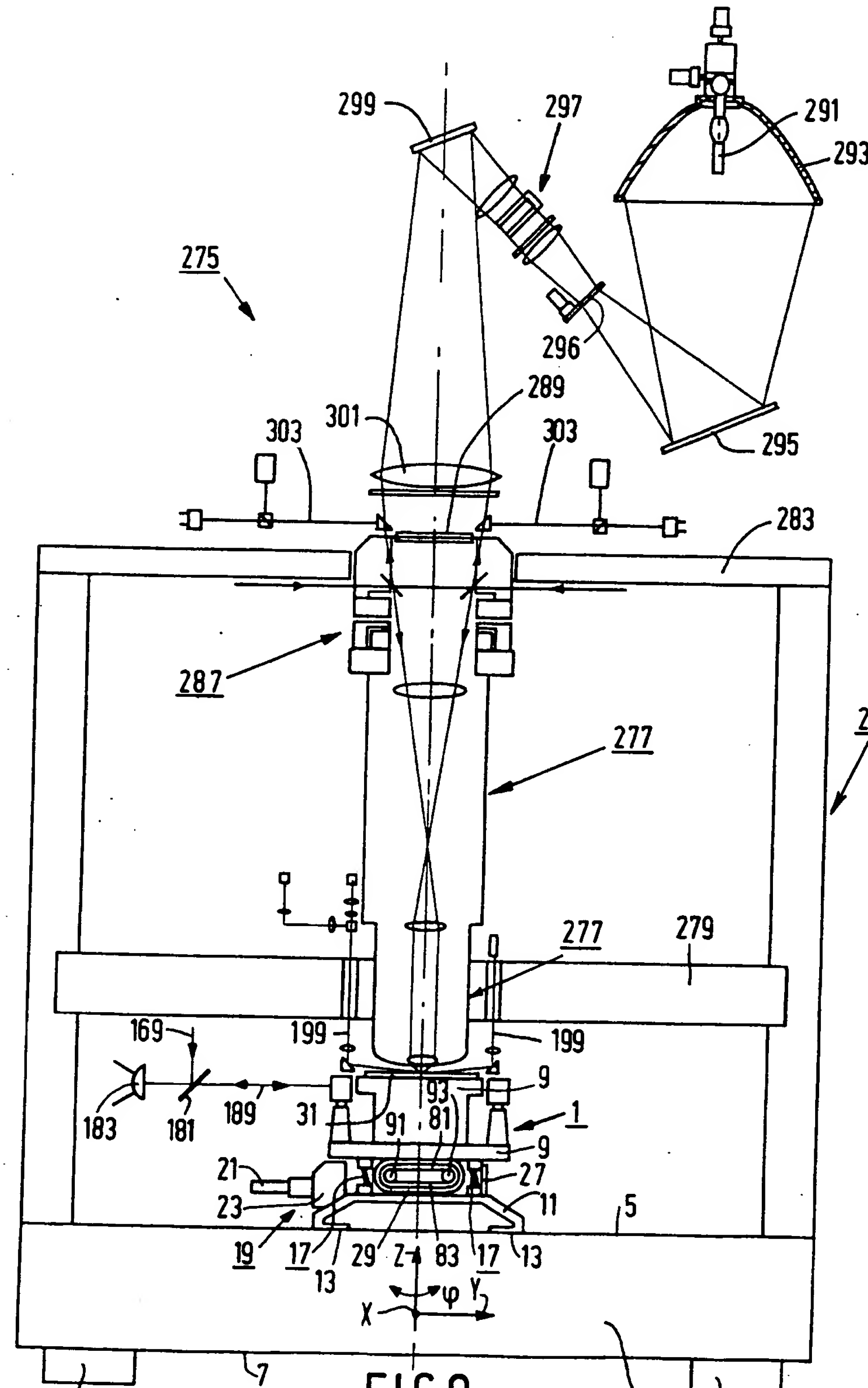

247
249
251
253
273
255
257
261
263
269
271
265
259
267
11
13
9
Y
141
143
17
Z
φ
X
5
3
17
141
143
25
13
7
23
21
126

FIG.8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φ
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FIG.9